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5G Millimeter Wave Range Capacitive Feed Printed Dipole Antenna Array

Armen V. Gevorkyan

Abstract – **In this paper, a design and radiation characteristics of an electrodynamics model of a capacitive feed printed dipole array element are presented. The array element is for operation in a millimeter wave range (25–26 GHz) of the fifth-generation communication systems for the wireless local network. It has a linear polarization. On the level of the VSWR less than 3, its operating frequency band is in the range from 23.325 to 28.201 GHz. In the needed frequency range, the value of the VSWR is no more than 1.3. Based on this array element was made the antenna array model with size 4 × 4. On the level of the VSWR less than 3, its operating frequency band is less than array elements and is located in the range from 23.778 to 27.865 GHz. In the needed frequency range, the value of the VSWR of its corner elements is no more than 1.6 and no more than 1.5 for all other elements. The value of the realized gain is in the range from 16.8 to 17.1 dB.**

Keywords – **Antennas, antenna arrays, capacitive feed, dipole antennas, millimeter waves.**

I. Introduction

The radio frequency range from 24.25 to 27.50 GHz is allocated for the creation of fifth-generation (5G) communication systems. These frequencies of the electromagnetic waves are greatly attenuated by building structures, which makes them suitable for use in wireless local area networks where neighboring networks may be situated close together (inside neighboring buildings, for example). Due to a sufficiently wide frequency band, it can be divided into smaller bands and create many such networks even within the same building.

There are a wide variety of antenna types that are suitable for usage in the millimeter wavelength range. These can be strip (patch) [1], [2], dipole [3]–[5], Vivaldi [6], [7], reflective [8] antennas, etc. The choice of the antenna type used depends on the requirements. Often, those antennas that can be made in printed form are selected.

When developing antenna arrays, the radiation characteristics (primarily VSWR) of their elements should have good repeatability. If the characteristics of an antenna array element are calculated as part of an infinite antenna array, then when creating a small element antenna array based on it, their characteristics often differ.

The difference is observed even for the central elements of the flat antenna arrays [9]–[11]. This was also observed in the previous study [12] on the development of the array element for the frequency range from 24.25 to 27.50 GHz. However, in this work, the VSWR values were small (VSWR ≤ 1.27). Therefore, for the central elements of the 16-element (4 × 4) antenna array, we can talk about a good coincidence of its VSWR with the VSWR of the element of the infinite antenna array. However, the remaining array elements had a higher VSWR value, although it did not exceed the level of the VSWR ≤ 2.

The aim of this study was to investigate the possibility of using a capacitive type feed to develop an array element with a minimum variation of VSWR values of its elements as part of the small element antenna array. To evaluate the characteristics, a frequency band with a width of 1 GHz in the range from 25 to 26 GHz was selected.

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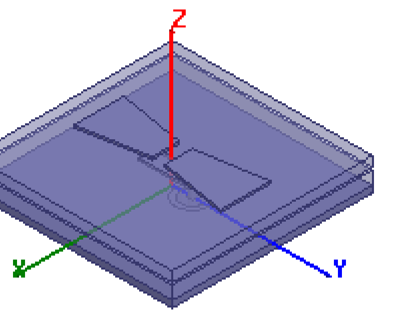
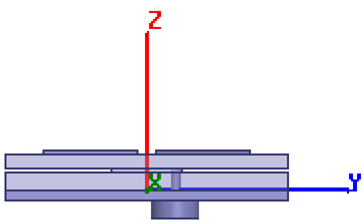
Armen V. Gevorkyan is with the Department of Antennas and Radio Transmitting Devices of Southern federal university, Taganrog, Russia, E-mail: gevorkyan.scp@yandex.ru.

II. Developed Array Element

The design of the developed array element electrodynamics model with a size of 6 mm × 6 mm is shown in Fig. 1 (6 mm is λ/2 in free space at a frequency of 25 GHz). The simulation was performed by electromagnetic software HFSS.



(a)



(b)

Fig. 1. The design of the array element:
(a) the general view, (b) the side view

It is constructed using two dielectric substrates (ε = 3.55). 50-ohm coaxial cable used for feeds. A coaxial cable core is connected to the conductor (0.8 mm × 1.5 mm), which is located on the lower dielectric substrate with 0.5 mm thickness. The trapezoid-shape conductors (0.5 mm (1.8 mm) × 2.2 mm) located on the upper dielectric substrate with a 0.2 mm thickness are the arms of the dipole. For it, fed used the electromagnetic field, which was excited by the lower conductor. That is, a capacitive feed is used [13]. A selected variant of its realization is also called "L-probe" fed [14]–[15].

As part of an infinite antenna array, the array element's characteristics were studied. The obtained frequency characteristics are shown in Figs. 2–5.

Figure 2 shows, it can be seen that the frequency characteristics of the VSWR have resonance with a central frequency equal to 25.450 GHz. Here, the VSWR value tends to 1. According to the level of the VSWR ≤ 3, the operating frequency band is in the range from 23.325 to 28.201 GHz. This fully includes the frequency range of 5G communication systems. For this range, the maximum value of the VSWR is equal to 2.34 and is observed at a frequency of 27.50 GHz. In the frequency range from 25 to 26 GHz, the value of the VSWR ≤ 1.3.

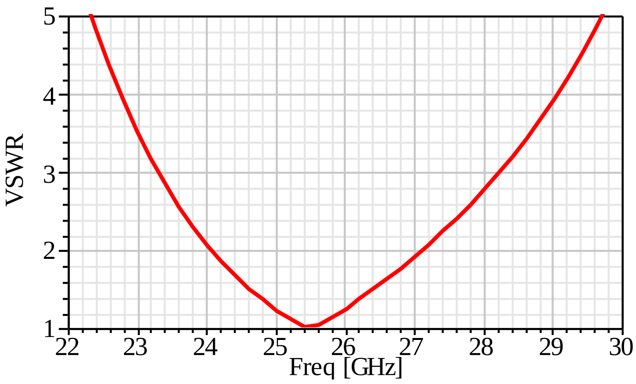


Fig. 2. The VSWR.

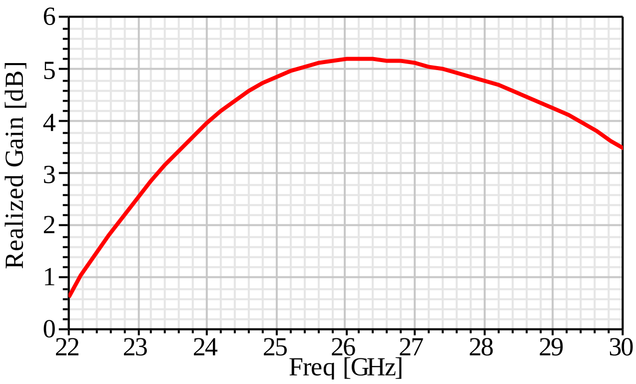


Fig. 3. The realized gain

It can be seen from Fig. 3 that the developed array element is weakly directed. The maximum value of the realized gain is not exceeding 5.2 dB.

The values of the cross-polarization level, which are shown in Fig. 4, indicate its absence. The polarization of the array element is linearly with the E-plane in the yz-plane (according to Fig. 1). Fig. 5 shows that the efficiency value exceeds 97.2% in the required frequency range.

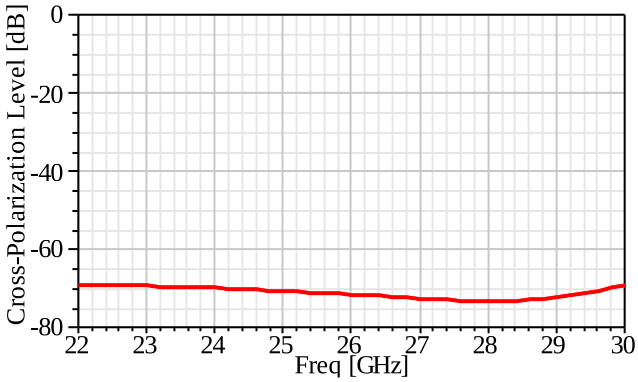


Fig. 4. The cross-polarization level

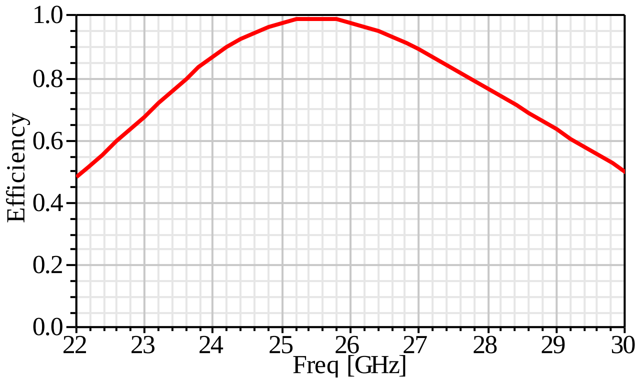


Fig. 5. The efficiency

III. Antenna Array

Based on the developed electrodynamics model array element, a 16-element (4 × 4) antenna array electrodynamics model was developed. It is shown in Fig. 6. Its frequency characteristics are shown in Figs. 7–12. Let's consider them.

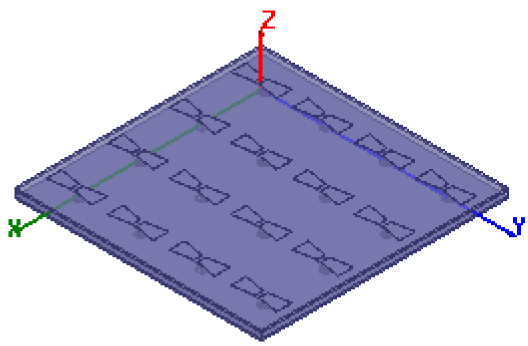


Fig. 6. The design of the antenna array

Figures 7 and 8 show the frequency characteristics of the VSWR and the reflection coefficient module of the all antenna array elements. The frequency characteristics of an infinite antenna array element are represented by lines with circles. They are given for comparison. The analysis shows that the greatest difference in characteristics is observed for the corner elements of the antenna array. I.e., for them, the edge effect is strongest, and at the edges of the frequency range from 25 to

26 GHz, the VSWR values are approximately equal to 1.6. For other antennas, the VSWR values do not exceed 1.5. For comparison, the element of an infinite antenna array has the values of the VSWR ≤ 1.3. Therefore, we can talk about an insignificant difference in the characteristics of the infinite and finite antenna array elements.

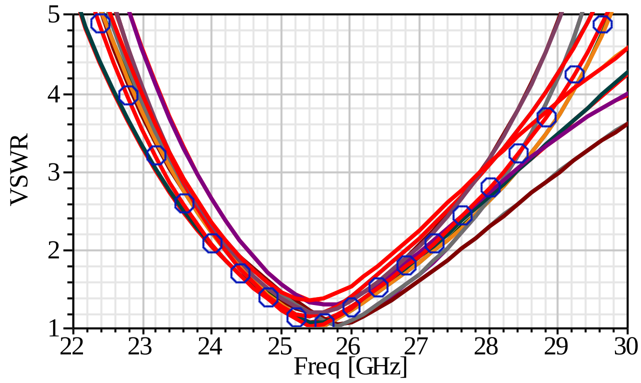


Fig. 7. The VSWR

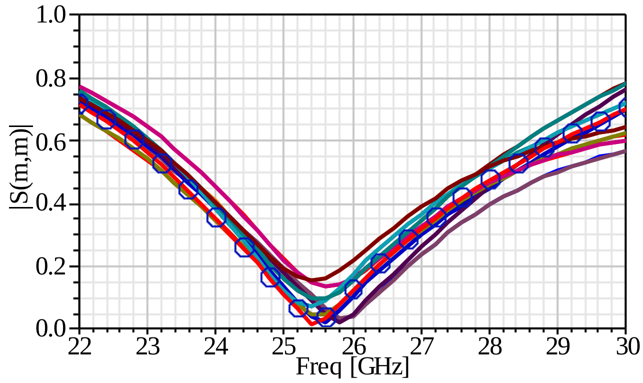


Fig. 8. The reflection coefficient module

Fig. 9 shows the frequency characteristics of the antenna array's realized gain (———). For comparison, its theoretically calculated value (— —) is given for an aperture of the same size as that of the antenna array. The difference between the characteristics in the frequency range from 25 to 26 GHz is the smaller (less than of 0.2 dB). The values of the realized gain are in the range from 16.8 to 17.1 dB. Beyond this range, they decrease significantly. This is due to the resonance of the VSWR frequency characteristics.

The antenna array, as the array element on the basis of which it is made, has a linear polarization. This is confirmed by Fig. 10.

Fig. 11 shows the frequency characteristics of the efficiency (———) and radiation efficiency (— —) of the antenna array. The efficiency value depends on the matching of the array elements to the power line, i.e., on the values of the VSWR (reflection coefficient) of all the array elements. As shown above, the VSWR (reflection coefficient) values in the frequency range from 25 to 26 GHz are small. The efficiency value is also determined by transmission coefficients between the antennas. It will be shown below that they have small values. Due to this and the small VSWR values, the efficiency of the antenna array tends to be 100% and is in the range from 95.8 to 97.7%. This is 1.4% less than the element of the infinite antenna array. This difference is also insignificant (it is at the level of calculation error). The radiation efficiency is also high and is in the range from 98.7 to 98.8%. This is due to the small thickness of the dielectric substrates and the low value of thermal losses in them. Thus, the final efficiency is at least 94.55%.

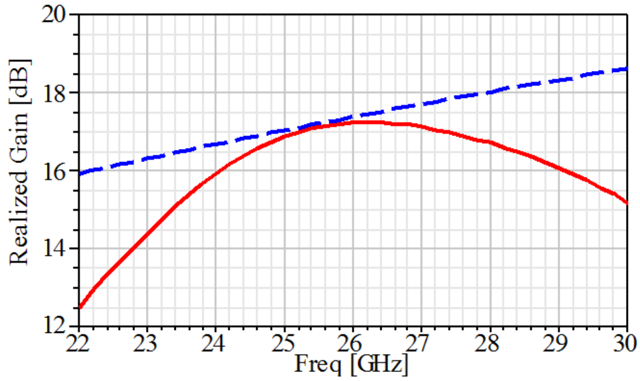


Fig. 9. The realized gain

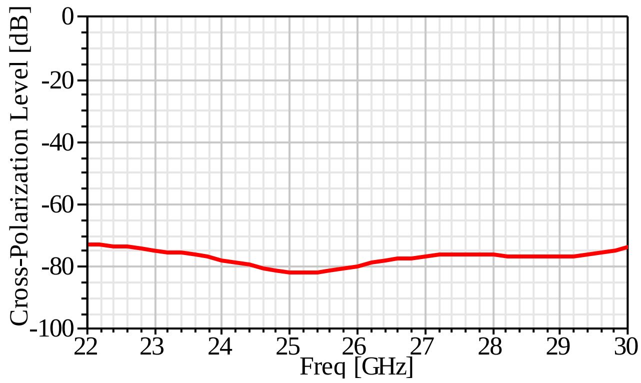


Fig. 10. The cross-polarization level

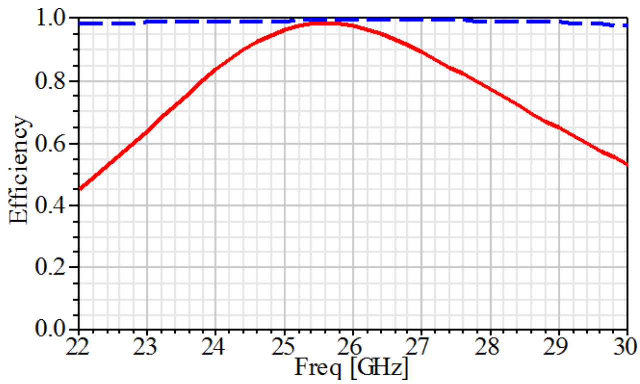


Fig. 11. The efficiency and radiation efficiency

Fig. 12 shows the frequency characteristics of the transmission coefficients between neighboring antennas (they are of the greatest value). The antennas at the edge of the E-plane antenna array are represented by the lines with the highest transmission coefficients in the range from 22 to 27 GHz. Their maximum value is equal to -16.8 dB. The value of the remaining transmission coefficients does not exceed -23.8 dB. Due to this, the developed array element can also be used to create MIMO antennas for 5G communication systems.

Fig. 13 shows the normalized radiation pattern of the antenna array in the E- (———) and H-planes (— —) at the frequencies of 25.0, 25.5, and 26.0 GHz. The graphs match inside the main lobe of the radiation pattern. Their difference in the inside of the first side lobes is related to the offset of the feed point of the bottom conductor. However, the differences are small. According to the analysis, the side lobe level is no more than -13.6 dB. For reference, the 3D radiation pattern at the frequency of 25.5 GHz is shown in Fig. 14.

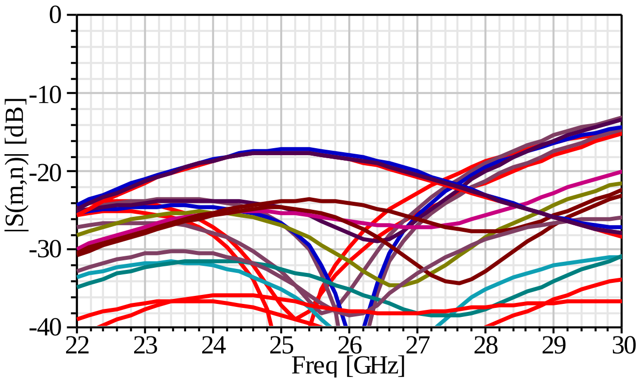


Fig. 12. The transmission coefficients

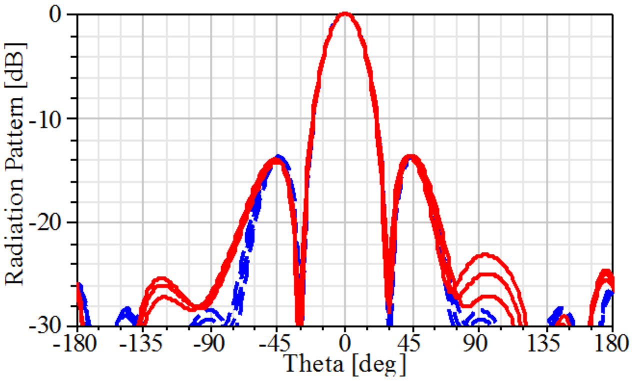


Fig. 13. The radiation pattern

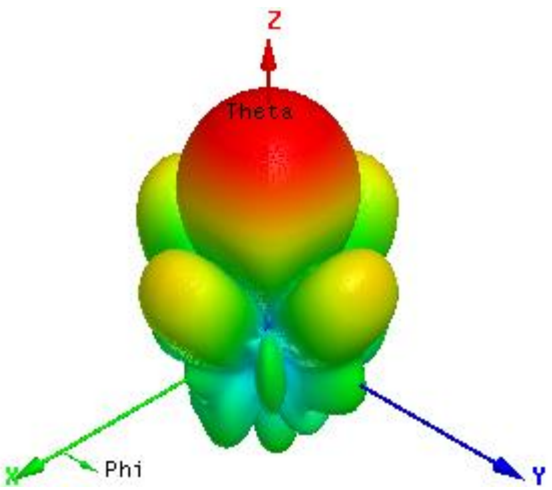


Fig. 14. The 3D radiation pattern

IV. Conclusion

In the course of the study, the electrodynamics model of the printed dipole array element with capacitive feed was developed. It is wideband and can be used in 5G communication systems.

Based on the developed electrodynamics model array element, a 16-element (4 × 4) antenna array electrodynamics model was developed. The study of its radiation characteristics showed a good agreement between the VSWR of its elements and the VSWR of the element of the infinite array. In the frequency range from 25 to 26 GHz, the maximum value of the VSWR of the array element / elements of the finite array is 1.30 / 1.60. In the previous work [12] it was 1.15 / 1.70. That is, the use of the capacitive feed allows you to achieve small scatter values of the VSWR of the array elements of the small element antenna array.

Acknowledgement

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